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there is no difficulty in getting the best lenses and instruments, providing an American or English microscope of large size and complicated structure is not chosen. It will be found that those only who use a microscope for amusement utterly condemn the simple instruments, while those who make investigations and gather wide experience often assert that the greater the simplicity the better. The European histologists I have met generally use a stand without rack and pinion for coarse adjustment, without movable stage and without movement round a horizontal axis.

As to books, Frey's Manual, of which there has been a translation published in New York, is only pretty good. It came into general use because it was for a long time without rivals. There have lately appeared two little works on this subject, in England, one by Professor Rutherford, the other by Mr. Schaeffer, both of which are considered good. But by far the most important work is Ranvier's Traité Technique d'Histologie now being published in Paris, in numbers, three of which have already appeared. The moderate price of the book, — only twenty-five francs for a volume of a thousand pages, — the fullness of detail, and the superb illustrations alone are sufficient to recommend the work. M. Ranvier has written a treatise which will probably always be remembered as one of the most important and valuable manuals ever published, and which ought to be owned by every one who attempts to investigate the elementary structure of animals.

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CONCERNING FOOT-PRINTS.

BY I. C. RUSSELL.

ICHNOLOGY (foot-print lore) is the name which has been applied to one of the most attractive and interesting paths of research that geology has pointed out. This branch of palæontology[1] has for its object the study and interpretation of the many fossil foot-prints that have been found in the rocks, which were impressed there by the feet of animals when the material of which those rocks are composed was the shifting sands along some ancient shore. The study of foot-prints has at length been recognized as a distinct and important branch of palæontology, one which has often afforded the only means for judging of the character and structure of the ancient animals that have left no other records of their existence than the impressions of their feet.

[1] From palaios, *ancient;* onta, *beings;* logos, *a discourse.*

The same principles of comparative anatomy that enabled Cuvier to reconstruct the skeletons of Tertiary mammals, a few bones of which were discovered near Paris, also give the ichnologist the power of calling again into being the forms of the animals which in times long passed impressed their foot-prints on the sand.

Let us see, first of all, how the records of these ancient footsteps have been preserved for indefinite ages, so as to appear as fresh and well defined as if made but yesterday. It is evident that if a track is left in the loose dry sand, it is poorly defined and soon becomes obliterated; but if impressed on the wet sand at low tide, or on mud of the proper consistence, it may retain its form for a considerable time. The first and most common means by which such foot-prints are indefinitely preserved is by the rising tide filling and covering the impressions with the mud and sand borne on by the advancing waves. Each tide by depositing a sheet of sediment over the trodden surface would not only tend to bury the foot-prints deeper and deeper and thus secure their preservation, but the new deposit thus spread out by the waters might receive a series of records in its turn, made by the feet of the birds and reptiles that walked over it, and by the drops of rain that pattered down on the plastic surface, or by the retreating wavelets that rippled over the soft mud. Such inscriptions when once entered on the day-book of nature are imperishable until the rocky tablets that they form are again ground down to sand and dust in the great cycle of changes to which they are subjected.

Such preservation of foot-prints can nowhere be better seen than on the shores of the Bay of Fundy, where, owing to the great difference between high and low tide, — in some places amounting to seventy feet, — a broad extent of smooth, shining mud is left exposed at low water. Some portion of this soft surface is sure to be trodden by the numerous birds that feed along the shore, or to have its surface pitted by a passing shower; often, too, the mud is left in regular ripples by the retreating tide, and sometimes a leaf is borne out by the wind and dropped on the plastic surface, to record the character of the vegetation that fringes the shore. The red mud with all these inscriptions upon it is somewhat hardened by the warmth of the sun, so that it retains its place when the advancing tide rushes in. As the waters then sift down the fine mud which they hold in suspension, it fills each foot-print and rain-drop impression, and imprisons the leaves that are fast on the bottom; and thus is finished another page in the records of the ages. When the tide steals slowly out, this deposit of silt is left behind with a smooth, glossy surface as before, ready to receive another series of impressions. This is not a rare or exceptional occurrence, but takes place nearly every summer's day on the shores of the great bay.

The constant accumulation of mud left in this manner by the retreating tides, although a single deposit may not exceed a sheet of paper in thickness, has yet formed thousands of acres of rich meadow-land, like the Tantramarsh and the broad meadows of Grand Pré, which retain, beneath their waving fields, the records made in the manner we have described, during hundreds and perhaps thousands of years before the Acadian farmers made that land their home. Sometimes upon splitting open the layers of hardened mud that form these meadows, the impressions made by the feet of animals are found; often, too, the bones of fishes are thus discovered, showing the manner in which the remains of the fishes that once swam in Devonian and Carboniferous seas have been preserved to our own day.

Another series of markings that are well displayed on the shores of the Bay of Fundy, and which are commonly associated with fossil foot-prints, are the shrinkage-cracks (or mud-cracks and sun-cracks, as they are often called) formed by the shrinking and cracking of the mud upon drying, when left exposed to the heat of the sun, — exactly as may be seen in every dried-up pool by the wayside. Such a net-work of intersecting fissures frequently covers many acres of the mud on the shores of the Bay of Fundy; and these modern mud-cracks often intersect and distort the foot-prints that have been previously formed, in precisely the same manner as the ancient foot-prints were sometimes distorted in the Triassic sandstone of the Connecticut valley.

The discovery of the stumps of pines and beeches rooted in what was once the surface of the soil, but now buried beneath the muddy deposits of the bay, prove, as pointed out by Professor Dawson, that the land has subsided and allowed the deposits to reach a greater thickness than they could otherwise have done. We can learn from this submerged forest a lesson that will be of value to us in all our geological rambles. It furnishes one of the many indications that the crust of our globe is not the *terra firma* it has been fancied to be, but is slowly rising in one place and sinking in another, and is sometimes pushed up into great folds from which mountains are formed. Recent research has shown that for hundreds of miles along the coast of Chili, the land is slowly rising; a similar movement is taking place in Northern Europe; while, on the other hand, areas of equally great extent in some portions of the Indian and Pacific oceans are slowly sinking. That a gradual subsidence and an equally gradual deposition have together determined the mode in which great thicknesses of sediments have accumulated during many of the geological ages is clearly shown by the formations that contain from base to summit the indisputable evidences of shallow water origin.

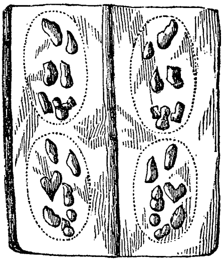
The material that is continually deposited by the waters of the Bay of Fundy is furnished, for the most part, by the wearing away of the rocks along the shores of the bay. This process can nowhere be better seen than at the picturesque promontory at Hopewell, situated at the head of Shepody Bay. The Carboniferous conglomerate there forms a bold headland, which is being rapidly eaten away by the waves at high tide, so as to make one of the most interesting bits of coast scenery that we ever had the pleasure of seeing. The waves have not only worn the hard conglomerate into many dark caves and ragged capes, but have also cut out high archways, forming natural bridges that connect outstanding masses of rock with the shore. In some cases these bridges are wanting or have been washed away; and what were once bold headlands are now separated from the shore, but still bear on their summits a crown of trees and shrubs that were once continuous with the vegetation on the mainland. The masses of rock thus separated from the shore — frequently calling to mind the outstanding "buttes" along the Green River, and in other cañons of the far West — form islands at high tide, and are worn away at their base by the action of the waves, so that each is supported by a constantly diminishing column of stone, which at length gives way, and brings down the huge mass into the reach of the waves, which fast reduce it to sand and mud, to be spread out once more by the waters. The pebbles that compose the conglomerate, after being imprisoned in the rock for unknown ages, are again rolled up and down the beach as they were in the Carboniferous days when they received their form. We were interested to observe the ripple-marks on the coarse rocks, made when they were the loose sand and pebbles on the shore of the Carboniferous ocean, only a few inches from the similar forms impressed upon the soft mud by the retreat of the morning's tide. So exactly alike were the ripples in each case that a person could with difficulty appreciate the fact that one series was formed millions of years before the other. The system of denudation and deposition so well illustrated at Hopewell Cape also furnishes a striking example of one of the most universal and far-reaching causes for the "imperfections of the geological record."

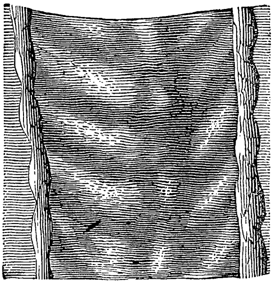
Another way in which foot-prints are preserved for long periods of time is by becoming filled with the fine sand and dust borne along by the wind, which by being drifted into the tracks penetrates their finest markings, and becoming covered with more blown sand, or by silt at high tide, retain, as already explained, an accurate mold and cast of the foot-prints, when the material shall have been hardened into rock. A counterpart of this second method of preservation can be seen when the newly fallen snow is drifted along by the wind and fills each cranny and crevice in the pavement; the snow gradually accumulates above, representing the sediment sifted down over the foot-prints on the shore, and sometimes becomes frozen into a solid mass, which when removed from the walks retains on its under surface an accurate cast of every line and crack on the stones beneath.

Still a third mode in which the impressions made by the feet of animals may be permanently preserved is seen when they are filled with fine sand and silt brought down by streams during sudden floods. The muddy waters then spread broadly out over the trodden sands, and cover them with a layer of fine mud; or, again, such a sheet of sediment may itself receive the impressions and be covered with sand by the incoming tide.

Layers of sand and clay when once deposited not only tend to become consolidated by the pressure of the mass that goes on forming above them, but are also penetrated by water bearing silica, lime, etc., in solution, which by being deposited around the particles of sand cement them together so as to form a compact sandstone; the strata of mud and clay may form at the same time beds of slade. Sandstones and shales being exposed to a high temperature or subjected to great pressure, are further metamorphosed and form quartzite and argillite, or the common slate used in the school-room. Throughout all these changes, however, the rocks sometimes retain the forms impressed upon them when they were soft sand and mud.

The oldest tracks known — excepting, perhaps, the trails left by annelid-like animals on the Taconic rocks of Vermont — were discovered some twenty-five years since in the Potsdam sandstone at Beauharnois, Canada, situated about twenty miles westward of Montreal. These foot-prints were made a subject of study by Professor Owen, and were considered by him as having been formed by a large crustacean, resembling very closely in structure the *Limulus*, or "king-crab," so common along the Atlantic coast at the present day. The tracks consist of a medial furrow, accompanied on both sides by a large number of small indentations. The entire series of impressions is about six inches wide, and has been followed in some cases for several feet. It will be noticed that the tracks on each side of the medial line have a definite rotation and form separate groups which regularly succeed one another, — each of these sets of impressions in the trail represented above being formed by seven individual tracks on each side of the furrow. From the nature of the impressions and the regularity with which they succeed each other, we conclude that they were made by an animal having either seven individual legs on each side of the body, or else a fewer number of limbs which were divided at their extremities; the latter theory is the one that Professor Owen considered most probable. The modern Limulus, whose trail resembles these ancient foot-prints almost exactly, has five pairs of true legs, four of which are forked at their extremities, while the hindmost pair is terminated by four lamellar appendages. The rigid tail of the Limulus leaves a furrow on the sand over which the animal walks corresponding to the central furrow in the trails on the Potsdam sandstone. That this ancient furrow was also made by a rigid tail, and not by the under surface of the animal's body, is shown by the fact that when a sharp curve was followed, the medial furrow swept to one side and sometimes obliterated the foot-prints on the convex side of the trail.


(Fig. 77.) PROTICHNITES SEPTEMNOTATUS, O. Potsdam.


(Fig. 78) CLIMACTICHNITES. Potsdam.

Several series of foot-prints of the same general nature as those shown in Figure 77 have been discovered at Beauharnois and at other localities in Canada; to all of these the generic name of *Protichnites* (*earliest foot-prints*) has been given. These trails differ among themselves, however, principally in regard to the number of individual tracks in the successive series of impressions. Some of the trails have seven separate indentations in each corresponding series, and are hence designated as *Protichnites septem-notatus;* others with eight impressions in each group, making sixteen as formed by all of the feet of the animal at the same time, are known as *P. octo-notatus;* others have received the name of *P. multi-notatus.* When we remember the great antiquity of these foot-prints, their discovery is seen to be of peculiar interest. The Potsdam sandstone on which they were impressed forms the base of the Silurian system in this country, and is almost the oldest formation in which well-defined fossils have been found. If we attempt to enumerate the centuries that have passed away since these delicate foot-prints were traced upon the sandy shore of the old Silurian ocean, we find ourselves as totally bewildered by the almost infinite lapse of time as we are when we endeavor to comprehend the distance of the fixed stars in space.

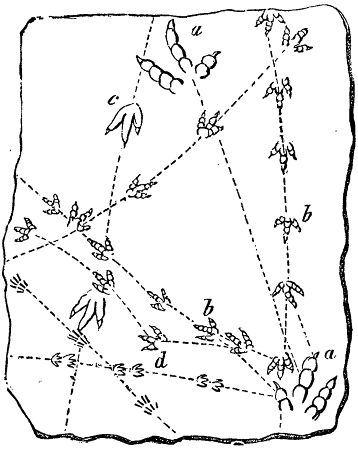
Splendid specimens of *Protichnites* can be seen at Montreal, in the rooms of the Geological Survey of Canada, to whose former director, Sir William Logan, we owe our knowledge of these interesting fossils. No one can examine those slabs of sandstone, with the strange trails sweeping across them, without some of that feeling of mingled wonder and awe which creeps over us when we see the inscriptions of some ancient people regarding whom tradition is silent.

These trails are not only interesting from their great antiquity, but also because they afford the only records ever discovered of the animals that made them. We find in the rocks that have afforded these foot-prints a few fossil sea-weeds, which mark the humble commencement of the flora of the globe, the shells of the Lingula, which are quite abundant at some localities and are the most common fossils from this formation, and also a few shells of other brachiopods, and some equally rare specimens of gasteropod shells. These lowly forms of life, together with a few species of trilobites, some of which, however, reached a very large size, make up the scanty fauna of those early days. None of the animals in this brief list could have left trails on the sand at all similar to those known as *Protichnites*, which owe their impression to some unknown crustacean of a higher degree of organization than any of the animals we have enumerated, which was literally the king-crab along the shores where it made its home.

The Potsdam sandstone has also yielded another series of foot-prints fully as large as *Protichnites*, called *Climactichnites*, in reference to their striking resemblance to a rope-ladder. These impressions (Figure 78) consist of two furrows, about six inches apart, the interspace crossed by parallel curved furrows that represent the rounds of the rope-ladder; there are also indications of a medial furrow, as in *Protichnites*. Of the animal that formed these trails even less is known, as can be inferred, than of those whose tracks we have been considering. They are supposed by some persons to be the track left by a huge trilobite, like *Paradoxides Harlani;* others consider them as the trail of a large gasteropod, no other records of which are known. Although the trail known as *Climactichnites* differs greatly in appearance from *Protichnites*, yet it is not impossible that they were formed by the same animal under different conditions: one impressed upon the sands while walking, the other, perhaps, formed by the swimming appendages, which are supposed to have resembled those of the Limulus.

As we have seen, the crustaceans were the highest forms of life in the Silurian oceans; their reign was terminated, however, about the close of the upper Silurian, by the introduction of fishes, which continued to be the rulers of the ocean throughout the Devonian age, which, for this reason, is often spoken of as the age of fishes. Another great advance was made in the life of the globe during the Carboniferous age, when the air-breathing reptiles first came upon the stage of being. The existence of these more highly organized animals in the Carboniferous age was first made known by the discovery of their foot-prints. The honor of first bringing these interesting relics to the notice of geologists is due also to Sir William Logan, who discovered reptilian foot-prints on slabs of Carboniferous sandstone in 1841, at Horton Bluff, Nova Scotia. Shortly afterwards, the well-known discovery of the foot-prints of a large amphibian, named *Sauropus primævus*, was made at Pottsville, Pa. For some time the foot prints of these ancient reptiles were the only evidence known of their existence. These scanty records, however, were enough to demonstrate that lizard-like reptiles, of considerable size and of a high organization, existed during the age in which the coal deposits of Nova Scotia and Pennsylvania were formed.

After a time the skeletons of some of the Carboniferous reptiles were brought to light. One of the earliest and most interesting of these discoveries was made by Lyell and Dawson, while examining the stump of a Sigillaria, one of the most common trees of the coal swamps, which had been buried in the sand that now forms the thick beds of sandstone at the South Joggins, Nova Scotia. The stump in question seems to have rotted away in the interior during the time when it was partially buried in the sand, so as to form a convenient retreat for the reptiles that made it their home, and in which they died as they were entrapped by the sand, which at length filled the stump and preserved the remains. Other skeletons of Carboniferous reptiles have since been discovered in considerable abundance at Linton, Ohio. A careful study of these remains has shown that there was no lack of diversity or of ornamentation and beauty among the reptiles that recorded their existence on the sands of the Carboniferous sea-shore, the authenticity of which has been so abundantly verified.



(FIG. 79.) SLAB OF TRIASSIC SANDSTONE WITH TRACKS OF BIRDS AND REPTILES.

In the Triassic period, which next succeeds the Carboniferous age in geological history, another great advance was made in the progress of life on the earth by the appearance of birds, which, as a class, stand next above the reptiles in the zoölogical scale. The existence of the feathered tribes during the Triassic period was first made known by the discovery of their foot-prints in the red sandstone of the Connecticut valley.

The Triassic formation in which these impressions were found fills the greater part of the Connecticut valley, and is again largely developed in New Jersey, affording in that State the red shales and sandstones so well known to travelers over the various railroads that radiate from Jersey City. It is this formation that furnishes the "brown stone" so largely used for architectural purposes in New York and the neighboring cities. The same formation stretches southward as far as Virginia and North Carolina, where it contains highly valuable beds of coal.

The foot-prints found so abundantly in the Connecticut valley frequently seem to have been impressed upon a layer of soft mud, now shale, and to have been covered with a layer of sand, now hardened into a firm sandstone, which, upon being raised from its native bed, retains upon its under surface, standing out in relief, an exact cast of the foot-prints. These natural casts are often as perfect as if molded in plaster, and sometimes retain even the lines and creases of the skin which covered the feet of the animals that impressed them. These tracks have not been found in a few rare instances, but number many thousands, obtained from nearly forty localities in the valley of the Connecticut; the writer has also obtained several species from Pompton and Plainfield, N. J.

We commonly hear these fossil foot-prints spoken of as "bird tracks;" they include, however, very many that are clearly reptilian in their character. Others have been referred to marsupial animals by Professor Hitchcock, to whose splendid report on the Ichnology of Massachusetts we would refer our readers for detailed and accurate information on this subject.

No skeletons of these ancient inhabitants of Connecticut and New Jersey have been found sufficiently well preserved to substantiate the conclusion of geologists that many of the tracks were made by birds, as the class is at present defined. Some persons are inclined to ascribe the bird tracks to kangaroo-like reptiles, which walked on two legs, like the gigantic *Hadrosaurus* that inhabited the shores of New Jersey in the next succeeding age, — the Cretaceous. Some fortunate discovery of the skeletons of these animals will possibly show that they possessed something of that strange "synthetic structure" so often met with in geological history. It is not improbable that these earliest of birds possessed a combination of reptilian and avian characters, exemplified by the *Archæopteryx*,[1] the *Pterodactyls*,[2] and the toothed birds from the Cretaceous formations of Nebraska.

The principal reasons that have led geologists to consider many of the Connecticut foot-prints as having been made by birds are that the animals were clearly bipeds, and left a tridactylous, or three-toed, impression on the mud; some of them had a fourth toe, connected with the metatarsal bone above the foot (as in many modern birds), which sometimes left a slight impression on the trodden surface. But the most striking analogy between the ancient tracks and the foot-prints of modern birds is to be seen in the fact that the phalanges, or joints of the toes, have the same numerical ratio in each; that is, in three-toed birds the inner toe has three, the middle one four, and the outermost one five phalanges.

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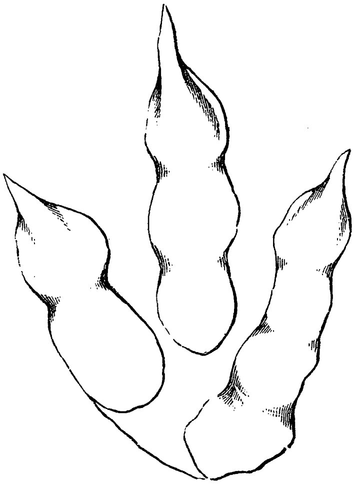
[1] A fossil bird found at Solenhofen, Bavaria, having short, rounded wings with claws attached, and a long lizard-like tail, composed of about twenty vertebræ, each supporting a pair of quill-feathers.

[2] A genus of flying reptiles belonging to the Jurassic and Cretaceous ages, which possessed membraneous, bat-like wings, that sometimes measured twenty-five feet from tip to tip.

The force of these arguments in favor of the ornithic character of the foot-prints has been somewhat impaired by the discovery of tracks bearing these peculiarities, but having, also, in connection with the large tridactylous impressions of the hind feet the much smaller five-toed tracks formed by the fore feet of the same animal, showing that they were made by a reptile. Sometimes a medial furrow accompanies such tracks, indicating that the animal possessed a long, strong tail. These discoveries, although proving that there have been three-toed reptiles, yet by no means prove that all the "bird tracks" were formed by such animals.

We learn from the Triassic foot-prints that the strange creatures that impressed them not only inhabited the Eastern States in great numbers, but also that there was great variety in that ancient fauna.



(Fig. 80.) BRONTOZOUM GIGANTEUM
TRIASSIC.

The accompanying figure of the foot-print known as *Brontozoum giganteum*, from Professor Hitchcock's report, represents the largest of the bird-like tracks found in the Connecticut valley. The foot-print represented in the figure as two and one half inches in length is in fact eighteen inches long and a foot in breadth, indicating, not only from the size of the foot-print, but from the manner in which the trodden surface was crushed down, and also by the length of the stride that separates the steps, a bird of gigantic proportions, that must have far surpassed in size the largest of living birds, — although probably not exceeding the dimensions of the *Dinornis giganteus*, which at no very distant time inhabited New Zealand.

"The giant ruler of the valley," however, was the great *Otozoum*, a huge biped reptile, whose foot-prints were each twenty inches in length by sixteen inches in breadth, and separated by strides three feet long; its great weight pressed down the sands as if an elephant had walked over them. Together with these gigantic foot-prints are found the tracks of other and much smaller denizens of the shore. The smallest of the Triassic reptiles, as indicated by its track, could not have exceeded a common frog in size. Associated with these are found the trails of worms and curious markings supposed to have been made by the fins of fishes, which we know inhabited the waters in great numbers.

The smooth, glossy surfaces of the slabs bearing the foot-prints have often received other inscriptions which are scarcely less interesting than the records of animal life. Frequently the surface of the rock is pitted with impressions made by falling rain-drops, and we can even tell the direction from which the wind blew during the time that those ancient showers watered the earth. The ripple-marks plainly tell that the soft mud was covered with water, which then, as now, broke in ripples on the beach. The sun-cracks no less clearly prove that the wet mud was left exposed to the heat of the sun, which caused it to shrink and crack, and that the surface was again covered with water which filled the cracks with sand and thus secured their preservation. These combined records show that the tide ebbed and flowed along those ancient shores, and that when it was at its lowest, it left exposed a broad stretch of shining mud, like that which borders the Bay of Fundy at low tide; upon this plastic surface the strange, uncouth monsters that emerged from the deep impressed the imperishable records of their existence.

We will leave to our readers the pleasure of picturing the strange scenes that filled the valley of the Connecticut in those distant days, when conifers, cycads, and ferns of tropical growth formed a varied and beautiful border to the valley and furnished shelter and food for the singular creatures whose footsteps we have followed.

To those who would drink deeper of this "foot-print lore," we recommend the writings of Hitchcock, Deane, Lea, Owen, etc.; or, still better than all, to pry open the leaves of the ancient tile library of nature, and interpret for themselves the cuniform impressions with which they are inscribed.